Anthropogenic impact on groundwater quality in the Oued Dfali watershed in the city of Taza, Morocco

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Abstract. This study was undertaken to determine the physicochemical quality of groundwater in the Oued Dfali catchment area, which is used by the local population for drinking and domestic purposes. Eleven sampling points, comprising wells and springs, were sampled during 2025. Around twenty physico-chemical parameters were analysed. The concentrations of these parameters vary from one sampling point to another and characterise these waters as being within a moderately acceptable range for certain parameters such as dissolved oxygen, conductivity, pH, hydrogen carbonate ions, chlorides and sulphates for the study period. However, for other parameters, the levels are unacceptable for human consumption, such as nitrates, aluminium, nickel and turbidity, which exceed the quality standards for drinking water. The main cause of this pollution is anthropogenic, stemming from hospital effluents (CHP Ibn Baja) and urban waste from the city of Taza, which poses a major risk to humans and the environment, particularly to water resources. The results obtained will be of great interest to health and hygiene services in taking preventive action to avoid serious health risks.

Key words. Groundwater, Wadi Dfali, contamination, human food, health risks.

1 Introduction

Morocco faces a multifaceted water crisis. The increasing scarcity, degradation and pollution of water resources pose a serious threat to the country's economic development and food security, particularly given the combined effects of climate change and the pressure exerted by human activities, which are leading to a growing volume of solid and liquid waste [1].

In Morocco, the National Water Strategy 2020–2050 serves as the framework for the country's sustainable water management and water security. The implementation of large-scale national programmes, such as the National Programme for Drinking Water Supply and Sanitation (PNAEPAL), launched in 2020 [2]. This programme aims not only to strengthen local capacities and extend access to drinking water in rural and urban areas, but also to improve sanitation infrastructure and raise public awareness of rational water use and hygiene measures, thereby contributing to the prevention of water-related diseases and the protection of receiving environments.

Indeed, like many Moroccan towns, Taza is not immune to this major problem of waste management in general, and wastewater management in particular; its wastewater is discharged without any prior treatment into neighbouring wadis, leading to groundwater contamination and risks to public health.

Water intended for human consumption must not contain dangerous levels of microorganisms or chemicals harmful to health [3]. Its contamination is the main source of diseases such as gastroenteritis, viral hepatitis, abdominal pain, typhoid and leptospirosis… According to UNICEF, in 2023, millions of infants and children die each year from diarrhoeal diseases, which are the fourth leading cause of death worldwide among children under five; these are primarily due to the unsanitary nature of water intended for human consumption and inadequate sanitation and hygiene systems [4].

The belief of the population that groundwater, which is the main source of fresh water, is traditionally the preferred water resource for drinking water, because it is protected from pollution thanks to the role of filter of the geological layers crossed. However, although they have been largely free of impurities, these waters contain elements that, beyond a certain level, significantly compromise their potability [5], and consequently their quality, which is implicated in several health conditions. Several recent studies indicate that groundwater pollution originates from geological and anthropogenic sources, including infiltration of

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wastewater and intensive use of chemical fertilizers in agriculture [6]. Moreover, this pollution is aggravated by the presence of poorly managed septic tanks, the deficit in treatment infrastructure, the inadequacy of sanitation networks and the non-compliance with public hygiene rules [1; 7].

Given that the problem of water pollution is a concern, especially for cities with waste management problems, it was deemed necessary to conduct an evaluation study on the level of groundwater contamination by physicochemical and bacteriological parameters mainly in the Dfali Wadi catchment area, the catchment area that receives liquid discharges from the Ibn Baja hospital without any Prior treatment to assess the impact of pollution on the groundwater in this catchment area to ensure the quality of this water used as drinking water and protect public health.

Materials and methods

1.1 Study area

The province of Taza is part of the region of Fez – Meknes. It lies between two distinct geographical and geological areas. This situation gives it an important role in the connection between eastern Morocco and other regions of Morocco [8].

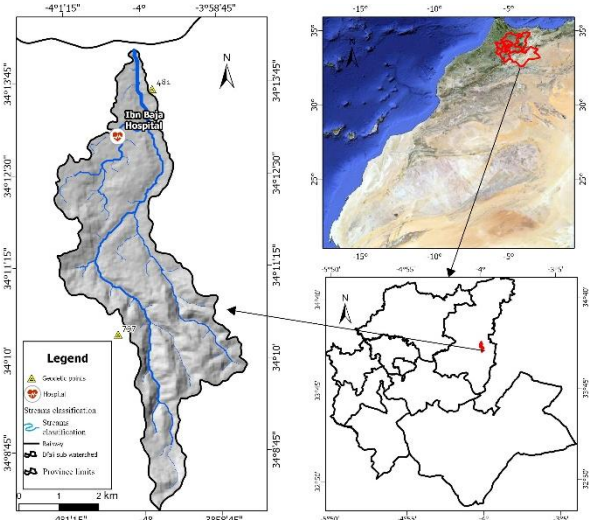
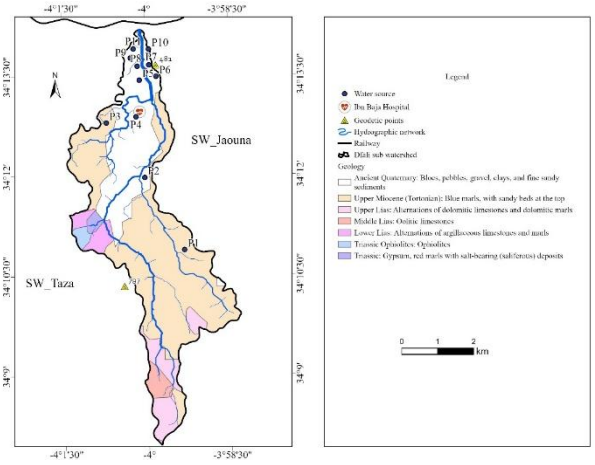


Fig. 1. Geographical situation of the Oued Dfali catchment area.

The Oued Dfali watershed is located in the province of Taza, in the Middle Atlas region, northeast of Morocco. Within the urban limits of the city of Taza, the Dfali watershed extends over about 28.28 km2 and originates in the Middle Atlas mountains and crosses agricultural areas before reaching the city of Taza [8] (Figure 1).The region experiences a Mediterranean climate, with relatively cool and rainy winters and hot and dry summers [8]. This climatic variability influences the quantity and quality of water available in the catchment area. Knowledge of the lithology of a watershed is important to know the influence of physiographic characteristics. The lithology of the substratum affects not only groundwater flow, but also surface runoff. In the latter case, the main geological characteristics are determined by the lithology (nature of the parent rock) and the tectonic structure of the terrain (Figure 2). The city of Taza is located in the narrow part of the South Rif furrow, commonly known as "Fez-Taza corridor", which materializes the junction between



the Rif areas to the north and Atlasique to the south.

Fig. 2. Geological map of the Oued Dfali watershed (from the geological map of Taza).

The geology of this region includes terrains of varied nature (limestone, shale, ...) and ages ranging from the Permo-Trias to the present, and marls from the lower and middle Miocene periods [9,10].

A high anthropogenic pressure and a particularly marked erosive dynamic characterize the catchment area of the Wadi Dfali. This basin is subject to progressive urbanization, evidenced by the presence of urban infrastructure such as sewerage collectors, communication routes and dwellings, which modify the natural hydrological functioning.

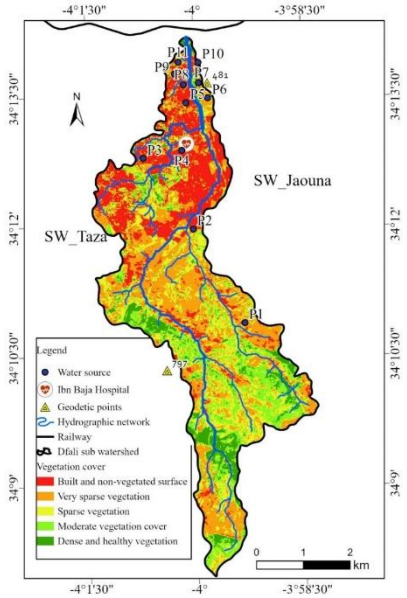


Fig. 3. Land use map of the Oued Dfali catchment area

Land use is dominated by agricultural activities, particularly cereal crops and tree farming, which extend over areas with low slopes and valleys. At the same time, urban extension contributes to soil waterproofing, thus promoting an increase in surface runoff [11] (Figure 3).

Plant cover, often sparse and degraded, does not provide effective protection against erosion agents. This situation is aggravated by the climatic characteristics of

the Mediterranean type, marked by intense and irregular rainfall episodes, which accentuate the phenomena of water erosion and sediment transport.
As a result, the catchment area of the Dfali Wadi is highly vulnerable to soil degradation and water quality deterioration, due to the combined effect of natural factors and human activities.
The physico-chemical composition of the plain waters was determined from 11 water points (Figure 4), well distributed in a way that provides better spatial knowledge of the current state of the quality of the analysed waters and also to have the impact of hospital and domestic discharges on underground resources in our study area.

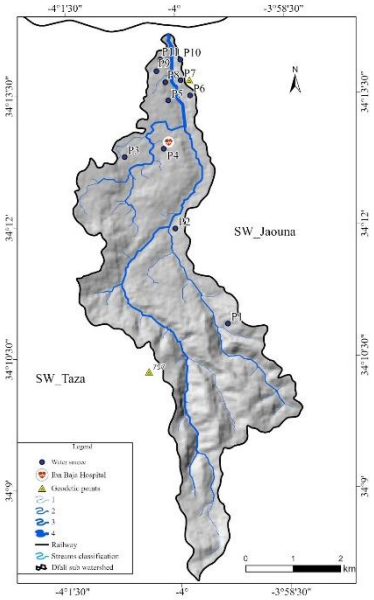


Fig. 4. Geographical location of the water points analysed

1.2 Experimental protocol

A good conclusion depends on good analytical results, which in turn depend on the proper collection of water samples. The samples were carried out in accordance with the Rodier standards and standard protocols issued by AFNOR and the ONEP procedures relating to sampling techniques for fixation, transport, preservation, and analysis [12,13]. Global physicochemical and microbiological parameters were measured: Ta, Te, pH, Sal, Cond, O2, NO3, TAC, TH, and CL- and the trace metal elements (Cd, Co, Cu, Fe, Ni,...) were carried out using induced plasma-coupled emission spectrometry (ICP-AES).

2 Results and discussion

The results of this study are presented by discussing the measured parameters, in particular the measurements carried out in situ and those carried out in the laboratory. We will cite the average results for groundwater in the Oued Dfali watershed.

The groundwater of the watershed of Dfali Wadi analysed is characterized by a pH ranging from 6.94 to 7.83, reflecting a neutral to slightly alkaline medium (Figure 5).

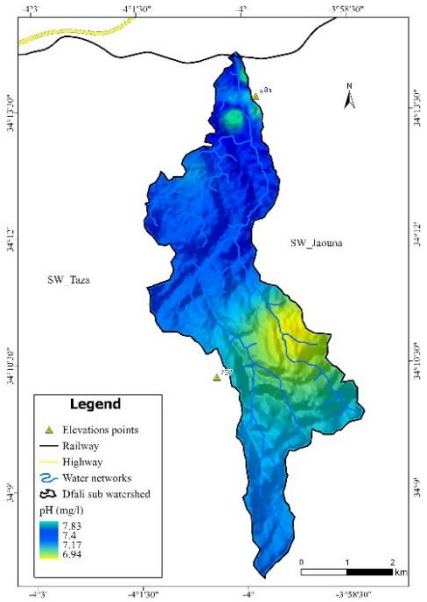


Fig. 5. Spatial evolution of the pH of groundwater in the catchment area of Dfali Wadi

This moderate alkalinity is mainly related to the water–rock interaction within carbonate formations of the Middle Atlas. The relatively low amplitude of about 0.89, which reflects a hydrochemical homogeneity between the analysed points that shows water circulation in comparable geological formations [1]. Furthermore, the recorded values remain in line with the Moroccan standard for human food water [3]. The recorded turbidity values range between 0.76 and 6.86 NTU (Figure 6), with a predominance of values below 5 NTU, reflecting an overall acceptable quality of the waters studied according to the Moroccan standard for human drinking water [3].

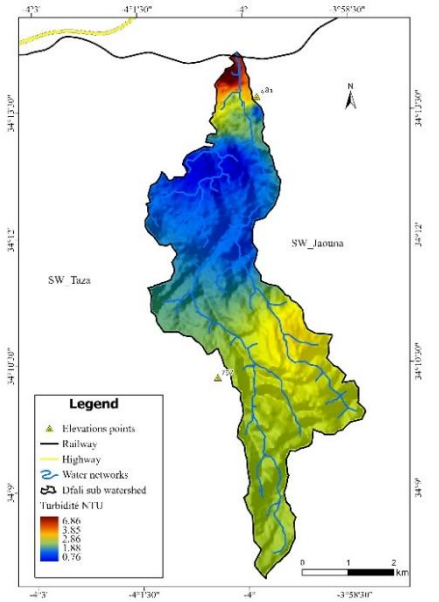


Fig. 6. Spatial evolution of groundwater turbidity in the Oued Dfali catchment area.

However, the presence of a point exceedance of the 5 NTU threshold (P11) suggests a likely local influence of suspended solids inputs mainly on the permeability of wastewater from the Dfali wadi or on point pollution.

The results show a globally moderately oxygenated water, with most values around the critical threshold of 5 mg/L. This reflects an aquatic system still functional but subject to moderate organic pressure, which can affect locally the self-purification processes.

The electrical conductivity values of the groundwater studied range between 787 and 1587 µS/cm, indicating a generally moderate mineralization to be elevated (Figure 7).

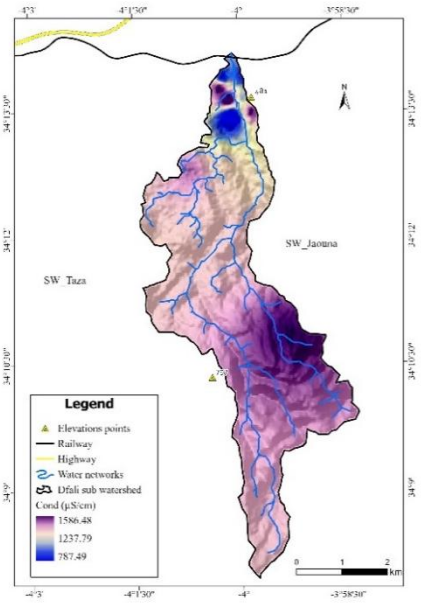


Fig. 7. Spatial evolution of groundwater conductivity in the Oued Dfali catchment area.

The majority of samples are in the medium mineralized water class, while one point shows higher mineralization, suggesting an increased influence of geological formation dissolution processes and anthropogenic inputs [14]. According to the Moroccan standard for human drinking water, these waters remain compatible for human consumption [3].

Chloride concentrations show a significant variability, with values ranging from 142 to 322 mg/L and an average of about 233 mg/L (Figure 8), while sodium levels (Na^+) range from 63.22 to 160.93 mg/L, for an average close to 121 mg/L.

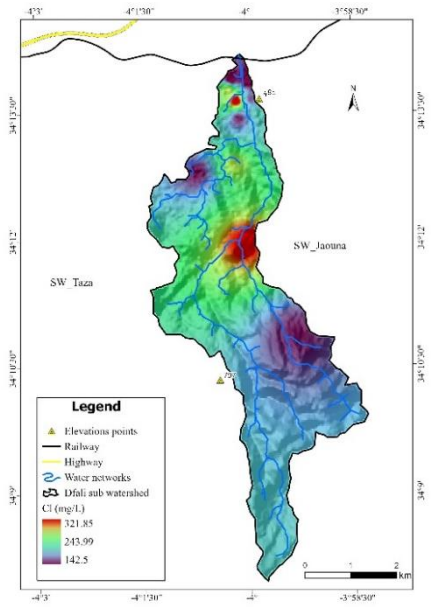


Fig. 8. Spatial evolution of chloride ions in groundwater in the Oued Dfali catchment area.

The average chloride values evolve in the same way as the conductivity for all measurement points. Chlorides could come from industrial discharges, percolation through salty land and the flow of irrigation water [14].

In the hydrogeological context of the Oued Dafli watershed, located in an urban environment within the city of Taza, the observed mineralization of groundwater is mainly explained by high anthropogenic pressure. This basin indeed receives direct or indirect inputs of raw wastewater of domestic origin, as well as liquid discharges from hospital structures, notably the Ibn Baja hospital, likely to enrich the environment with dissolved salts and ionic compounds.

Alongside these anthropogenic inputs, natural processes such as water–rock interaction and the gradual dissolution of geological formations also contribute to the groundwater chemical signature of this watershed [15].

The results show relatively high concentrations of calcium (84–177 mg/L) and magnesium (22–50 mg/L) (Figure 9), reflecting a strong influence of the dissolution processes of carbonate rocks [16]. These elements confirm the existence of natural mineralization related to water–rock interactions. However, their association with high levels of chlorides, sodium and electrical conductivity indicates a superposition of anthropogenic inputs, particularly in the urban context of the Oued Dafli watershed, which is subject to domestic and hospital discharges.

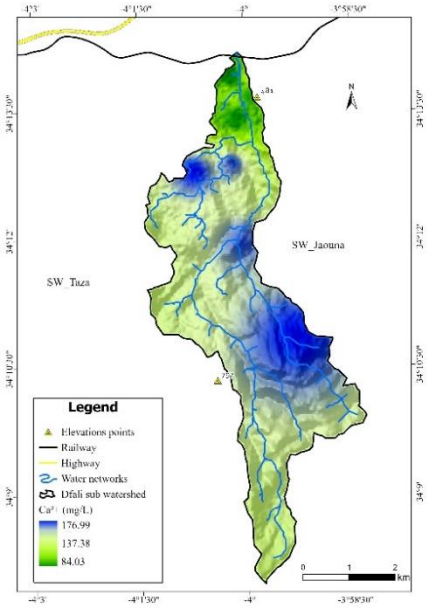


Fig. 9. Spatial evolution of calcium ions in groundwater in the Dfali Wadi catchment area.

Bicarbonate concentrations (201–463 mg/L) reflect a high concentration of bicarbonates (HCO_3^-) clearly reflect the dominant influence of carbonate geological formations, mainly made up of limestone (Figure 10) and (Figure 2). Indeed, limestone rocks react with water charged with carbon dioxide according to a natural dissolution process, leading to the formation of bicarbonate ions in solution. However, in the context of the situation of the Oued Dfali watershed in the urban environment, this natural geological signal may be partially modified by anthropogenic inputs, but the bicarbonate signature remains a strong indicator of the influence of limestone soils on groundwater mineralization.

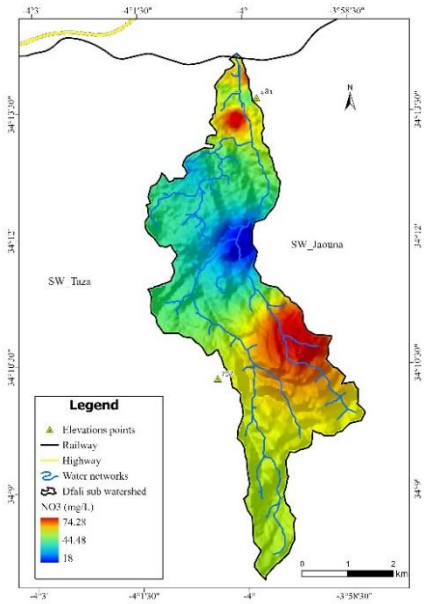


Fig. 10. Spatial evolution of bicarbonate ions in the groundwater of the Oued Dfali basin.

Nitrate ($NO3^-$) concentrations measured in the groundwater of the Dfali River basin show significant variability, with values ranging from 18.00 mg/L to 74.30 mg/L (Figure 11), and 54.5% of the analyzed water slightly exceeds the drinking water limit set at 50 mg/L by the World Health Organization and the Moroccan standard for human food waters [3], indicating a deterioration in the quality of groundwater from some wells and springs in the Wadi Dfali watershed. This situation reflects the dominant influence of anthropogenic activities, which would reflect a recent contamination resulting from the infiltration of wastewater and a lack of dissolved oxygen in the environment. The spatial distribution of nitrates highlights an increased vulnerability of the catchment to leaching and infiltration processes, favored by the steep slope [1,18].

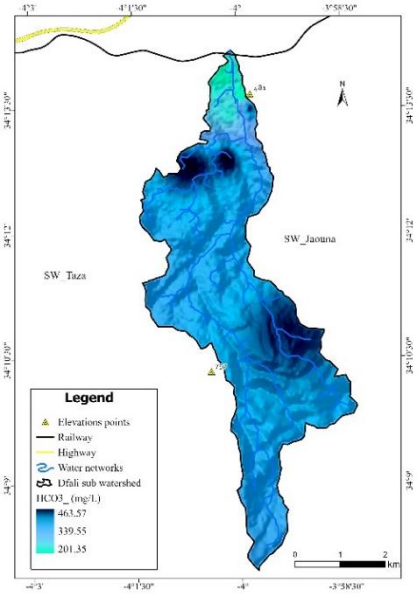


Fig. 11. Spatial evolution of nitrate ions in the groundwater of the Oued Dfali basin

These results indicate a significant deterioration in water quality and require the implementation of appropriate management and protection measures as well as awareness-raising among the surrounding population.

Sulfate ion concentrations in the groundwater of the Wadi Dfali basin show significant variability (Figure 12), with values generally in line with human food standards [3], but showing locally significant exceedances. The origin of sulfates is mainly related to the dissolution of marly and evaporitic geological formations, which shows the low concentration of sulfate ions because our catchment area belongs to the Middle Atlas, characterized by a limestone-rich terrain. although secondary anthropogenic inputs cannot be ruled out [18].

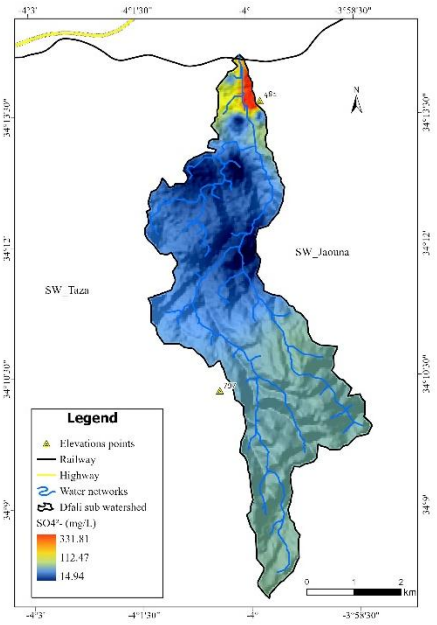


Fig. 12. Spatial evolution of sulphate ions in the groundwater of the Oued Dfali basin.

The spatial distribution of sulphates, combined with high nitrate levels, highlights a double influence, natural and anthropogenic, controlling the chemical quality of groundwater in this basin.

The measured metal trace elements showed a metallic pollution of the groundwater analyzed compared to the Moroccan standard for potability [3]. The detailed analysis of trace metal elements in the groundwater of the Oued Dfali basin highlights a heterogeneous chemical quality. The results show a marked nickel contamination in several points (Figure 13), localized aluminum pollution (P5), as well as significant natural mineralization reflected by high strontium concentrations.

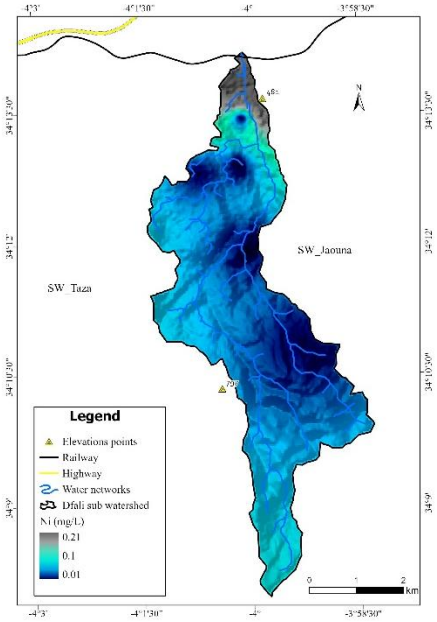


Fig. 13. Spatial evolution of nickel ions in the groundwater of the Dfali Wadi catchment

Vanadium and cobalt concentrations also indicate a combined influence of geological and anthropogenic factors. This reflects the percolation of raw wastewater through the different layers according to their degree of permeability [19]. This situation confirms the aquifer's vulnerability to environmental pressures and requires regular monitoring.

3 Conclusion

The assessment of groundwater quality in the Oued Dfali watershed reveals a significant alteration of their chemical quality, resulting from the complex interaction between natural geogenic processes and increasing anthropogenic pressures.

The mineralization parameters indicate electrical conductivities between 787 and 1587 µS/cm, reflecting a moderate increase in mineralization, corroborated by significant concentrations of bicarbonates (201–463 mg/L), calcium, and magnesium.

Nitrates have concentrations ranging from 18 to 74.30 mg/L, with several exceedances of the Moroccan standard (50 mg/L), notably at points P1, P6, P10 and P11. This nitrogen contamination reflects diffuse pollution of agricultural and domestic origin, reflecting an increased vulnerability of the water table to infiltration of surface contaminants.

Sulphates show a marked variability (14.93 to 332.41 mg/L), with high localized values (P7 and P10), suggesting a combined contribution from the dissolution of gypsum formations and anthropogenic inputs.

Regarding trace metal elements, the results highlight a heterogeneous but worrying contamination. Nickel is the most critical element, with concentrations reaching 0.2138 mg/L, far exceeding potability thresholds (0.02 mg/L) and indicating widespread contamination at several sites (P5–P11). Point anomalies are also observed for aluminum (up to 0.7602 mg/L), manganese and vanadium, reflecting both lithogenic contributions and anthropogenic inputs. Conversely, strontium has high concentrations but is consistent with the carbonate geological signature of the basin.

The physico-chemical parameters (neutral to slightly alkaline pH, moderate oxygenation and generally low turbidity) suggest relatively stable hydrochemical conditions, although likely to be disturbed by external inputs.

Overall, the results indicate that groundwater in the Wadi Dfali catchment area is generally affected by a degradation of its quality, characterized by a combination of high natural mineralization and significant anthropogenic pressures, especially agricultural and urban.

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